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DECISION AIDING CONCEPTS FOR AIR STRIKE PLANNING

December 1980

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This report describes the design of an air strike plan decision aid system integrating ideas and techniques developed in the ONR ODA program. The general air strike planning problem is structured to identify and classify objectives, constraints, decisions, and influencing factors. Using the structure, decisions are divided into five problem areas: target selection, weapon allocation, mission formation and assignment, mission routing and scheduling, and contingency planning. A decision aid system called the Air Strike Planner (ASP) is presented as a flexible approach —> next page

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to strike planning, enabling the strike planner to attack the decision area in any sequence and level of detail desired. To describe at a more detailed level the ASP approach to a strike planning aid, the weapons allocation portion of ASP is described as a stand-alone aid called the Weapons Allocation Aid for Strike Planning (WAASP). Special attention is given to areas where ODA aids, techniques, and principles might be suitably applied.

EXECUTIVE SUMMARY

This is a progress report on the current status of work directed toward the development of a comprehensive decision aiding system for air strike planning. In the course of the ONR Operational Decision Aids program which began in 1974, a variety of decision aiding concepts and systems have been developed for different aspects of the air strike planning process. In 1979 a plan and program to integrate the existing aids and to produce other needed components for a comprehensive air strike planning aid were generated. Although a design for such an aid has been developed and is presented in this report, it has become clear that some important components must still be developed. A concept for a component aid for weapons allocation decisions is discussed in some detail because of the pivotal role of weaponeering in the strike planning process. Although just two complementary decision aid designs are presented in this report, it should be noted that there are many problems in the strike planning process and there are a variety of aiding techniques that can be applied to any single problem. Furthermore, comprehensive aids for strike planning, incorporating sophisticated aiding techniques, require large investments both for development and implementation. Since the magnitude of anticipated benefits from any of the decision aiding alternatives is unknown, it is recommended that continuing efforts focus on the generation of designs for major decision aiding alternatives for strike planning and the analysis of cost-benefit tradeoffs for those designs.

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1. INTRODUCTION

The Operational Decision Aids (ODA) project was initiated by ONR in 1974 to coordinate an intensive application of relevant technology to the problems of the Naval decision maker. After several years of effort, a number of separate decision aids and aiding concepts were generated that demonstrated how a variety of techniques could be applied to operational aspects of Naval warfare problems. Some of the aids dealt with specific problem situations such as emission control decisions for task force ships while others, such as an aid for generating and analyzing decision trees, dealt with general techniques that could be applied to a broad range of problems. Because most of these aids were either directly or indirectly relevant to some aspect of air strike planning, an investigation was initiated in 1978 to assess the feasibility of constructing an integrated aid for air strike planning. The first year of effort on the integrated decision aid, documented by Glenn and Zachary (1979), focused on characterizing the candidate aid components and exploring the objectives and issues associated with aid integration. The present report documents the aid integration efforts of the past year during which time specific designs for a comprehensive strike planning aid were generated.

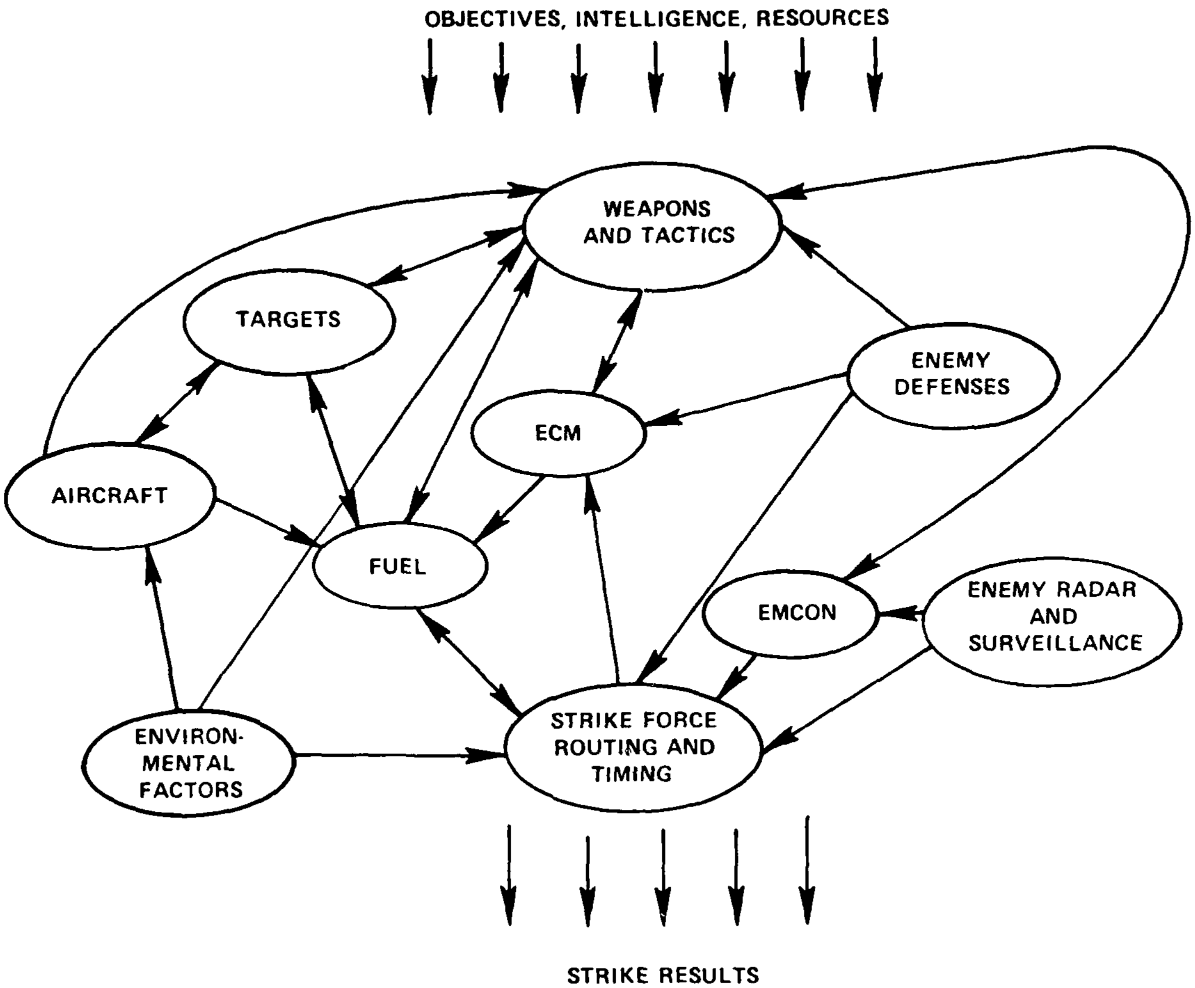


Figure 2-1. Interrelations of Strike Planning Factors

2. PROBLEM

Air strike planning has as its objective a desired level of destruction or obstruction inflicted upon enemy forces. In most cases, destruction of enemy material (ships, tanks, missile sites) is the objective, but targets may also include bridges, roads, railroads, and airfields which are important to the enemy's operations. Indeed, the strike alone may be of strategic value in throwing the enemy off-balance and hindering operations even if damage inflicted is negligible. The objectives for the strike may be developed by the planner or they may be dictated by some other authority. There are three basic forms the objectives may take:

- Maximization -- damage the enemy as much as possible.
- Threshold Attainment -- damage the enemy at least to a specified degree.
- Desired Level -- damage to the enemy should exceed a specified threshold, but should also be below a specified ceiling.

Air strike plans must meet problem constraints to be feasible. These constraints are of four types:

- Resource Availability Constraints
  Limits exist on the numbers of aircraft, weapons, and other equipment that may be used in the plan. These limits may be imposed either by material inventory or by other planning constraints (such as requirements for task force defense).
- Cost Constraints
  The objectives must be attained while limiting the losses in personnel and resources.
- Strike Time Constraints
  Often the strike must be completed by a specified time to be effective or to satisfy higher-level plans.

- Solution Time Constraints
  Because the strike plan must be completed well in advance of the planned launch time, there is often a severe time constraint on the planning process.

Decisions must be made on assignments, routes, and schedules to produce an air strike plan that simultaneously achieves the strike objectives while remaining within the bounds of the constraints. Each air strike consists of a central strike mission supported by such missions as escort, command and control, refuel, and search and rescue. For each such mission, the following decisions must be made:

- Strike Mission
  -- Selection of weapons and gear for attack aircraft
  -- Assignment of weapons to targets
  -- Routing and scheduling of attack aircraft to and from targets
  -- Engagement tactics
  -- EMCON tactics

- Escort Mission
  -- Assignment of weapons and gear to fighters
  -- Assignment of escort mission to strike mission
  -- Routing and scheduling of fighters
  -- Engagement tactics
  -- EMCON tactics

- Command and Control
  -- Routing and scheduling of command and control platforms
  -- EMCON tactics

- Refuel
  -- Routing and scheduling of tanker aircraft
  -- Assignment of tankers to missions needing refuel

- Search and Rescue
  -- Contingency plans.

Influencing these decisions are a host of interrelated factors. Figure 2-1 illustrates some of the many interactions between these factors (e.g., as weapons assignment influences fuel requirements for strike aircraft via factors such as weight and drag) with the arrows indicating directions of

potential influence. It is this complex interrelationship of decisions and factors that provides the great challenge in air strike planning.

3. AN APPROACH TO THE AIR STRIKE PLANNING PROBLEM

3.1 PROBLEM STRUCTURE

In developing a decision aid for the air strike planning problem, the first step taken was to divide the large, overall problem into several more manageable, though still interrelated, problems:

- Target selection
- Weapon allocation
- Mission formation and assignment
- Mission routing and scheduling
- Contingency planning.

3.1.1 Target Selection

The strike planner decides on the set of targets to be attacked based on several criteria such as:

- Value of target destruction
- Number of aircraft within normal range of the target
- Applicability of available weapons to target destruction
- Enemy force levels in target area and en-route to target area
- Enemy sensor capability en-route to target area
- Weather in target area and en-route to target area.

3.1.2 Weapon Allocation

Selection of available weapons must be performed to achieve the objectives. It is also generally necessary to allocate some weapons to suppression or destruction of enemy ground defenses. Those weapons must then

be assigned to the available aircraft. The strike planner must also consider the weapon loading capability of the aircraft. Aircraft are limited with regard to types, numbers, and combinations of weapons they carry. The weapons may also affect flight performance such as speed, altitude, acceleration, fuel consumption rate, and maneuverability. The weapon loading also limits engagement tactics to be used. Weapons are not the only stores loaded on an aircraft. The planner may also consider loading of external fuel tanks, sensors, chaff, flares, and cameras. The above discussion applies to fighters as well as attack aircraft.

3.1.3 Mission Formation and Assignment

An air strike is generally comprised of at least three component missions: an attack mission, an escort mission, and a command and control mission. If the strike plan calls for multiple approach routes to the target, multiple waves of attack, or multiple targets that are geographically separated, then there may be an appropriate multiplicity of attack and escort missions. The plan may also designate missions to perform supporting functions such as refueling, ECM, and search and rescue. Major tasks of the strike planning process are the identification of the types of mission that are appropriate for a given strike objective and the specification of the types and numbers of aircraft to be used for each mission. The formation and assignment of missions, however, are generally complicated by their many interactions with other aspects of strike planning (e.g., as the requirements for refueling and ECM missions depend on route selection and intelligence concerning enemy defenses).

3.1.4 Mission Routing and Scheduling

The mission route is the path taken from launch to objective and return. The mission schedule must coordinate the route with time by listing:

- Time of arrival at target,
- Time of arrival at refueling point,

- Time and nature of route changes (direction, speed, altitude),
- Timing of EMCON plan,
- Time of launch,
- Time of landing, and
- Time of reaching holding station (command and control, refuel).

Among the considerations weighed by the decision maker in selecting a route and schedule are:

- Enemy sensor location, range, and capability,
- Altitude and speed effects on sensor detection,
- Enemy force levels, range, and combat ceiling,
- Refueling points,
- Alternate landing sites,
- Mission organization points,
- Fuel consumption of aircraft,
- Cruise and combat ceilings of aircraft,
- Tactics of attack on target,
- Speed limitations of aircraft,
- Terrain types,
- Weather conditions, and
- Coordination requirements for simultaneous strike missions.

3.1.5 Contingency Plans

Although the principal emphasis of a strike plan must be on events that are judged most likely to occur, it is also important for the plan to

offer responses to the less likely possibilities. A comprehensive strike plan will include contingency plans of the following types:

- Specification of secondary targets and conditions for diverting the strike to them.
- Indication of variations in strike tactics if the weather conditions at the target are much different than anticipated.
- Specification of conditions under which EMCON should be prematurely broken.
- Specification of conditions (if any) which warrant the abandonment of the entire strike or a component mission.

3.2 DESIGN APPROACH

The key design features employed in the development of the decision aid concepts described in this report were modularity and flexibility. The design uses a modular approach to permit the strike planning process to be pursued as the iterative solution of the various subproblems discussed in Section 3.1. Each functional module is identified with one of these subproblems. The separate functional modules are linked together to provide cohesion to the system as a whole; an executive module, thus, acts as the central node of the system. Since all of the functional modules require access to much of the same information, a centralized data base located within the executive module is visualized. As each functional module is used, the planner makes different decisions about the air strike. To record these decisions, temporarily or permanently, a work area termed the Air Strike Plan Data Area is reserved in the executive. Once the decisions about the strike plan are made, another functional module is needed to evaluate the strike plan. To perform this function, a module is envisioned to simulate strike engagements that might be achieved by the strike plan and to provide potential results to the planner. Figure 3-1 diagrams this functional approach to the decision aid design.

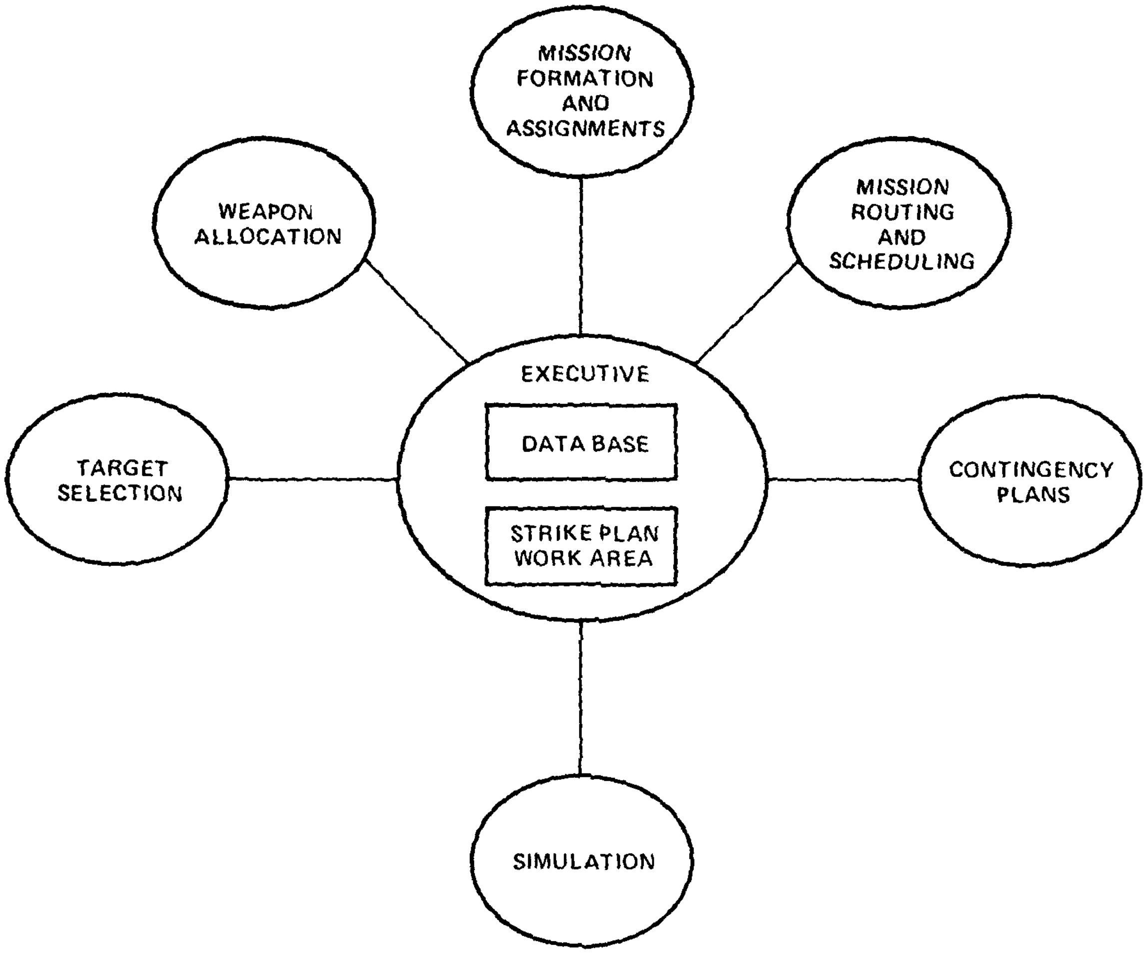


Figure 3-1. A Functional Design Approach to an Air Strike Planning Decision Aid System

The second key aspect of the design approach is flexibility. Because of the many interrelationships among the air strike planning subproblems, the planner should be able to define one aspect of the problem, to move to another aspect, and then possibly to return to further refine decisions already made or to see how subsequent decisions affect earlier ones. An air strike planner does not necessarily take the same approach to different air strike problems and different air strike planners will generally not take the same approach to the same problem. The design approach in Figure 3-1 allows this flexibility in planning and decision making styles. The planner may start with any of the functional modules to define part of the air strike plan. These decisions are recorded in the Air Strike Plan Data Area so that they may be accessed by any of the functional modules subsequently used. The planner has complete freedom in developing the air strike plan through use of the functional modules in any order.

The flexibility principle extends to the level of detail the planner wishes to pursue. A strike plan need only be completed to the level of detail deemed necessary by the planner, not by the system. The system is designed to be a forgiving system which will make reasonable defaults or assumptions for parameters and details not specified by the planner.

3.3 AIR STRIKE PLANNER (ASP)

Using the approach of Section 3.2 decision aid design principles were applied to each of the functional modules presented in Section 3.1. Much initial research in these areas was performed under ONR's ODA program. Where applicable, the ideas and techniques developed in the ODA program were integrated into the proposed functional modules. The resulting system is the Air Strike Planner (ASP). ASP is proposed as one reasonable application of decision aid principles to the air strike planning problem.

3.3.1 Air Strike Plan Data Areas

One of the functions of the ASP Executive is to construct and store descriptions of strike plans as they are developed by the user. These descriptions are implemented in records called Strike Plan Data Areas. When the user initiates ASP, the Strike Plan Data Areas of the system are empty. The Strike Plan Data Areas are capable of storing several alternate complete air strike plans, each containing specifications of:

- Targets,
- Weapon allocation for each aircraft,
- Mission composition,
- Mission routing,
- Mission scheduling, and
- Contingency rules.

With the aid of the various modules of ASP, the planner completes the specification of one or more air strike plans. These plans can then be tested using the simulation module.

A Strike Plan Data Area may be completed using several techniques:

- Computer-generation of plan based on standard Navy doctrine,
- Computer optimization,
- System default values or rules,
- Retrieval from data base,
- Generation by decision maker, or
- Duplication from another Strike Plan Data Area.

The above techniques may be used on an entire plan or on user selected portions of a plan; they may be used independently or in combination. Once completed, hard copies of the air strike plan may be printed.

3.3.2 ASP Data Base

The ASP Data Base is a modified version of the ODA Data Base developed by CTEC (1976). It is assumed that portions of the data base are continually updated with sensor and intelligence data. When the decision maker initiates an ASP planning session, a "snapshot" of these portions is made for use during the session. A new snapshot may be made upon request of the user at any time. Standard plans may be devised and stored in the data base (e.g., standard weapon loading). The Data Base also is used to store standard value or utility models.

In order to keep the user informed of important changes in dynamic data, programs called alerters developed by researchers at the Wharton School (Buneman and Morgan, 1977) are incorporated in the Data Base Interface. These programs can be set by the user to generate alerts whenever particular conditions of special interest to the user obtain. One application is to allow the decision maker to be informed when "frozen" dynamic data has changed significantly. Because development of a strike plan can require considerable time, the user can freeze certain dynamic data elements during his analysis but with the capability to be advised if any data changes sufficiently to warrant re-initiating the analysis. A second application of alerters is to signal changes in dynamic data that are likely to impact significantly the expected result of a strike after planning is complete. Here, tolerances on data elements can be obtained from sensitivity analyses of a complete simulation, whereas in the former case standard rough tolerances (e.g., + or -10 percent) would probably be used.

3.3.3 ASP Modules

From the user's viewpoint, ASP appears as a collection of separate but interrelated, problem-oriented modules. These modules, in fact, are

comprised of some overlapping software (e.g., shared I/O functions), but the user interacts with each module as a distinct subsystem in solving a coherent problem. A set of basic ASP modules is oriented to the planning of a single air strike as listed below:

- Target Selection - The mission planner must establish the targets of the air strike as they depend on objectives, geography, and resources.

- Mission Composition and Assignment - The decision maker must form the mission composition that will ensure the most target destruction at an acceptable level of losses.

- Weapon Loading of Aircraft - Weapon loading may be tailored for the missions to be performed. These specifications add precision to the measures of platform effectiveness and performance.

- Mission Routing and Scheduling - With mission targets and aircraft performance capabilities defined, the paths of the mission to and from their objectives may be defined along with the timing of the route. Contingency plans are also defined at this point.

- Simulation - Using a specified air strike plan, the air strike may be simulated in either an analytic or a stochastic mode.

A possible auxiliary set of ASP modules could build on the capabilities of the basic set to enable the decision maker to consider a broader array of problems. These modules may include:

- Campaign Planning - An air strike campaign, consisting of a sequence of air strikes over an extended period of time can be described and the outcome simulated.

- EMCON Planning - Strikes against the task force that might be launched by the enemy can be analyzed in order to determine an effective EMCON policy.

- Decision Structuring - Decision trees for any problem situation can be developed and analyzed. Such a tool is useful in weighing major tactical alternatives at many levels of decision making.

3.3.3.1 Target Selection. The main device to aid the decision maker in the selection of targets is the geographic display of the theater of operations. A suitable graphic device may be used upon request to display:

- Locations and designations of enemy and friendly forces,
- Locations and utility values of targets,
- Contours displaying the number of attack and/or escort aircraft, possibly combat value weighted, capable of reaching different areas,
- Contours displaying the number of defensive elements, possibly combat value weighted, capable of reaching different areas,
- Contours displaying the net advantage or disadvantage of offensive vs defensive elements in different geographic areas, or
- Weather patterns.

Any combination of the above features may be presented at one time on the display. The user places constraints on the displayed feature such as displaying strike contours for a single task force as distinct from those for combined task forces. The display can be enlarged or reduced to focus on a section of the theater of operations.

Sensitivity analysis can be further performed to test the effect of individual elements. Such a feature is especially helpful for evaluating the effect on the strategic situation of destroying a specific target.

The tabular display can be used in combination with the geographic display for more detailed specification of force levels and compositions. For example, a force designated by a symbol on the geographic display may be subdivided into its component parts on the tabular display. Hard copies of these displayed tabular data can be requested. This complementary use of tabular and graphic displays is adapted from the Options Selection Checklist decision aid (developed by Grumman Aerospace Corporation -- Kalenty, Lockwood,

and Vissering, 1977). This technique permits effective consideration of the factors involved in selection of targets, as described earlier. The user is allowed to select several sets of targets, one set for each alternate strike plan. The planner may also request computer generation of target sets. Such automatic procedures necessitate definition of a value model by the decision maker in order to provide a criterion for optimization; alternatively, a standard pre-defined value model can be stored in the data base. Using the ASP deterministic engagement model, target sets are rated according to the expected utility of the specified air strike on those targets.

3.3.3.2 Mission Formation and Assignment. The missions that may be assigned are:

- Strike (assigned to a particular target),
- Escort (assigned to protect a strike mission),
- ECM (assigned to protect strike and escort missions from weapons that are electromagnetically targeted),
- Command and Control (assigned to guide escort and strike missions),
- Refuel (assigned to refuel a set of missions), and
- Search and Rescue (assigned to rescue personnel from downed aircraft).

The decision maker must decide which missions are necessary to accomplish the objectives of the air strike plan and which aircraft must compose the missions to achieve the best chance of success.

The display features used here are similar to those used for force location and range information in the Target Selection Module. In composing air strike missions, much consideration is given to the interaction of different aircraft with the target and defense systems. Thus, the decision maker selects a target set and then requests the display of the aircraft

types and numbers which may reach the selected targets. Probabilities of kill (or amount of total damage) can also be presented in this display. If the air strike plan associated with the target set has weapon allocation specified, the weapon loading will be taken into account for the probabilities of kill; otherwise, standard loadings will be assumed.

If Strike or Escort force levels appear inadequate, the decision maker may consider the use of additional aircraft that were initially rejected because of their range limits. Given the set of Strike and Escort missions, the module generates refueling missions for logistic support. The precision of the refueling estimates depends on the level of specification of routing in the air strike plan.

Given the targets, the module can also function automatically to generate a baseline mission assignment and composition based on standard Navy procedures. This baseline solution can then be adapted to suit the current situation.

3.3.3.3 Weapon Allocation. Once the targets and missions have been specified, a further refinement of the plan is performed by specifying the armaments and stores to be carried by the aircraft. A tabular display of the standard weapon loading of each aircraft type in a mission is presented along with a comparison of the total loading demands and the actual supply. Thus, one situation necessitating changes in weapon loading occurs when demand exceeds supply. Such a display can also indicate the damage or probability of kill resulting from the weapon against the target and indications of the weapon loading effect on aircraft flight performance. A separate display can be requested indicating the inventory levels of weapons at different sites. The decision aid can also be used to allocate other stores such as ECM gear and sensors. The loading of all stores will be checked to assure that the configuration for the aircraft in question is a feasible one. The decision aid will also account for extra equipment needed to load stores when calculating aircraft flight performance effects.

Decision aiding systems have been developed in the past for weapon loading problems, so it may be possible to adapt existing systems for the weapon loading module of ASP. Several systems have been developed by the Joint Tactical Coordinating Group (JTCG, 1977, 1978) to assist in formulating and analyzing weapon loading plans and an algorithm for optimizing weapon loading has been developed by the Center for Naval Analyses (Bram, 1965).

3.3.3.4 Mission Routing and Scheduling. Using the geographic display, the decision maker can plot mission routes in two dimensions. The tabular display can be used to define mission flight status at launch, target, landing, holding stations, and intermediate points defined by the user on the geographic display. The status at each such point contains clock time and altitude; holding stations also must include time of stay at the station. Speed and altitude changes may then be interpolated from these points. Any inconsistencies imposed by these time-distance-altitude constraints are brought to the attention of the decision maker. Fuel consumption along the route may also be calculated. Any aircraft which cannot complete the route without refueling will have its range circle about the last intermediate point plotted on the geographic display to indicate possible refueling points consistent with the current route. These refueling points are then added to the aircraft's route (with time and altitude) to complete the route. The addition of a refueling point may force the alteration of other points in the route. The refueling point also defines the objective of a refueling mission which may then be routed.

Detection rates of sensors are presented on the geographic display as contours to guide the decision maker in selecting a route that minimizes probability of detection. Once a route is scheduled, several measures of its effectiveness are generated and displayed. Cumulative probability of detection along a route is calculated and displayed by marking levels of probability along the route or color coding the route according to detection probability. A single numerical rating of a route for detection is calculated by weighting

probability of detection by either distance en route to target or time en route to target. Combining detection probabilities with enemy force locations, the module produces areas of highest likelihood of engagement along a route. Such areas can be displayed as color-coded line segments along the route.

The user can also request the module to generate mission routes and schedules. These solutions would not necessarily be optimal, but would provide the decision maker with a baseline solution that might need only slight modification. Research addressed at determining the appropriate allocation of optimization functions for mission routing between man and machine has been performed by Integrated Sciences Corporation (Walsh and Schechterman, 1978; Schechterman and Walsh, 1980). Results to date indicate that the machine should be used to calculate an effectiveness score for each candidate route and, for a simplified version of the problem, it is equally efficient to have the man alone or the machine aided by the man perform the search for the optimal solution.

3.3.3.5 Simulation. The air strike may be simulated in either analytic or stochastic mode. Either mode of simulation may be used as the basis of a wargaming analysis.

The analytic mode is used for quick estimation of the effectiveness of an air strike plan. All calculations of outcomes are deterministic. The SRI Strike Outcome Calculator (Garnero, Bobick, and Ayers, 1978; Garnero, Rowney, and Ketchell, 1978) may be incorporated in this role.

The stochastic mode is a Monte Carlo simulation of the air strike plan, which produces distributions of detailed outcomes. The user can request outcome displays which are continually updated as the results of each new trial are obtained. This feature provides two functions:

- Continual and immediate involvement of the user with the simulation results (thus minimizing user frustration that occurs

when the user waits for a system response without knowing what the computer is doing).

- Ability of the user to stop the simulation when a sufficient level of usable results has been obtained.

The user can also automatically limit the number of iterations of the Monte Carlo process. The ASTDA engagement model (Epstein, 1978) would be used as the basis for this mode.

The wargaming capability is especially helpful in enabling the user to study the possible responses of enemy defenses to the air strike mission and the probabilities of their use. The effect of planned deception is especially well modeled in this mode. In the wargame mode, each "player" is provided with his own set of displays. The information presented on the display consists only of that which the players would be capable of detecting. The air strike player is committed to the strike plan used but must also consider the possibility of an air strike from the opponent. The defending player must concentrate on stopping the impending strike but may also send a strike out as well. Thus, the wargame serves as a defensive as well as an offensive aid.

3.3.3.6 Campaign Planning. ASP can represent sequences of strike missions in order to deal with waves and prongs of a single attack and with multi-strike campaigns. As with single strikes, the user has the option of selecting between deterministic and stochastic modes of simulation for multi-strike campaigns. However, when dealing with multiple strikes in the stochastic mode, it is probably necessary to restrict the number of iterations or to allow a very large amount of computer time for the simulation. For sensitivity and intra-process analyses, the deterministic mode of simulation is required. The simulation techniques employed in the SRI Strike Outcome Calulator (Garnero, Bobick, and Ayers, 1978) are appropriate for the representation of contingency plans and supporting operations.

3.3.3.7 EMCON Planning. Two types of EMCON planning are relevant to air strike missions, ship EMCON and aircraft EMCON. In general, ship emissions are controlled to prevent the enemy from identifying ships which it knows from its own radars to be present. Thus, ship EMCON plans seek to prevent the enemy from identifying the task force's highly valued units (and, hence, from targeting strikes against them) while still allowing the task force to maintain adequate surveillance of enemy activities. Aircraft emissions, on the other hand, are controlled mainly to prevent the enemy from detecting the presence of the aircraft, especially in the case of a strike mission. ASP deals with both types of EMCON plan, but in very different ways. Aircraft EMCON is represented directly in the strike simulation by treating electromagnetic emissions in the same manner as enemy radar and by postulating that when strike aircraft emissions are prevented there is a consequent degradation in strike force coordination, timing, and response to enemy threats. Ship EMCON is analyzed chiefly by simulating enemy attacks on the task force to evaluate the tradeoff between surveillance effectiveness and enemy ability to identify highly valued units. For these functions the Electronic Warfare (EWAR) decision aid developed by Decision-Science Applications (Noble et al., 1978; Noble, 1980) should be incorporated in ASP. Although ship EMCON is not directly relevant to the offensive air strike mission, it is appropriate to treat the problem in ASP because EMCON decisions are concerned with enemy air strikes against the task force and the same types of simulation tools are relevant to both offensive and defensive considerations.

3.3.3.8 Decision Structuring. In considering major alternatives for air strike tactics and interactions between the air strike and other task force operations, it is desirable to have a system to assist the decision maker in the development and analysis of decision tree structures. Such a system could help in the initial determination of what targets to strike, the choice of major tactical options, and the impact of strike force absence on the defensive posture of the task force. The decision structuring aid developed by SRI (Merkhofer et al., 1977; Merkhofer et al., 1979) accordingly helps the

decision maker to investigate all potentially important scenario factors, to identify worst-case conditions, and to determine promising tree branches for further development and analysis. Probabilities associated with tree branches and values for terminal nodes are supplied primarily as subjective estimates because decision structuring occurs early in the planning cycle and is conducted at a very coarse level of detail. The decision structuring aid should be fully integrated into ASP, however, to permit simulation outputs to be used in decision tree analyses in cases where sufficient detail is available, such as in the choice between distinct strike tactics.

3.4 WEAPONS ALLOCATION AID FOR STRIKE PLANNING (WAASP)

Due to the broad scope of the ASP concept, the preceding discussion of ASP has dealt only with fairly general features of the system. For several reasons, it is desirable to develop further details regarding implementation and usage for a portion of the ASP system. First, a detailed conception of one ASP component will suggest to some extent how the complete system might be developed in comparable detail. Second, a clearer presentation may be given on how the system may be used to achieve strike planning objectives. Third, an example may be provided on how existing decision aids may be integrated into the system.

Furthermore, it may be appropriate to undertake software development of ASP in a piecemeal fashion to demonstrate the value of aid concepts for strike planning problems prior to full-scale implementation. In order to effect such a demonstration, each step of the sequential development should end with a functionally useful subsystem capable of being implemented and tested. As a first step in this direction, a concept for a stand-alone decision aid addressing a single strike planning problem was deemed appropriate.

Informal discussions with Navy officers who have planned air strike operations have revealed a definite need for assistance in weapons allocation decisions. Yet, weapons allocation was one area of strike planning which had

received little attention in the ODA program. By selecting weapons allocation as the problem addressed in the first step of ASP development, two goals may be achieved:

- Demonstration of decision aid techniques to be used throughout ASP.
- Development of a decision aid for a problem needing attention.

3.4.1 Problem Definition

Weapons allocation, in its most general sense, deals with the assignment of weapons and other equipment to all aircraft involved in the strike plan (i.e. all attack aircraft and supporting aircraft). However, most interest has centered on the loading of attack aircraft. Thus, to limit the size of the problem while still displaying decision aid techniques of use in strike planning, the weapons allocation problem addressed here considers only attack aircraft.

Although a considerable amount of data exists to aid in the selection of weapons for a preemptive carrier-based air strike, the task of selecting the critical mix of weapons that can be delivered effectively by available aircraft against the designated targets continues to be difficult and time-consuming. The problem is the complexity of considering a multitude of interrelated variables, intermediate decisions, and a large volume of relevant supporting data (tables, nomographs, mathematical models, etc.) in a mission-oriented, timely fashion. This complexity provides many opportunities for human error by misinterpreting data. Because of the problem complexity, so much time is spent determining a single viable mix of weapons for a strike that the ability to search for an optimal weapons mix is limited. There are, fortunately, several decision-aiding techniques that can be implemented to alleviate this situation.

Currently, there are several aids for performing weapon effectiveness calculations. These aids serve to automate calculation procedures described in the Joint Munitions Effectiveness Manual/Air-to-Surface (JMEM/AS), which in turn has been developed and maintained by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). These aids, referred to as the JMEM Weaponeering Aids, include:

- One developed by the JTCG/ME (JTCG/ME, 1977) -- a collection of documented programs to be used with small programmable pocket and desk calculators (such as the Wang 700 and 720 and the Hewlett Packard HP67 and HP97).
- A second aid is the PROCAL JMEM Basic Analysis Program developed by the Naval Ocean Systems Center (NOSC, 1980).
- A third aid, developed by the JTCG/ME (JTCG/ME, 1978), is the Automated Weaponeering Optimization Program (AWOP), designed for batch or interactive processing on large mainframe computers (such as a CDC 6600 or an IBM 360).

All of these aids require the user to input target and weapon characteristics, weapon delivery conditions, and either desired target destruction or number of sorties attacking the target. The outputs from these aids assess the probability of each sortie destroying the target, and assess either the total expected target destruction based on the number of sorties or the number of sorties required to achieve total desired target destruction.

The ορτι{ιζατιον capability of the AWOP system consists of εναβωινλ τηε ρωαννεθ to perform the same probability computation for a single target with differing weapon types, weapon delivery conditions, and number of weapons per attack pass. When multiple weapons are delivered in a single attack pass, which is the normal tactic, AWOP determines automatically the optimal time interval for spacing the individual weapon launches. The planner then optimizes by searching manually for the case which maximizes probability of target damage or which minimizes the number of required sorties within the constraints the planner imposes on weapon and aircraft availability

and on delivery conditions. For example, the user may choose a slightly sub-optimal delivery condition if the optimal delivery condition increases the vulnerability of the delivering aircraft above an acceptable level.

The JMEM Weaponeering Aids, just now becoming available to the fleet, should prove highly beneficial in strike planning because they serve to automate the complex weapon effectiveness calculations, thereby eliminating time-consuming manual efforts that are prone to error. The absence of an automated optimization capability for the weaponeering aids for small computers and calculators is a significant deficiency because of the complexities discussed earlier. Although the principal optimization capability of AWOP -- exhaustive search -- is not sophisticated, the variety of feasible conditions generally is sufficiently limited and computer processing is sufficiently fast so that the time requirement for optimization is acceptable for most strike planning problems. Thus, as far as it goes, AWOP provides an effective weapons optimization tool for the strike planner.

The major shortcoming of the JMEM Weaponeering Aids, and of AWOP in particular, is that no mechanism is provided for considering exposure of attacking aircraft to enemy defenses. It must be assumed that valuable military targets are generally protected by surface-to-air missile (SAM) sites and/or anti-aircraft artillery (AAA). It follows that the most accurate delivery mode for unguided weapons often requires high exposure to enemy defenses which introduces several options to reduce the expected number of aircraft attrited by enemy air defenses:

- Minimize exposure of aircraft to defenses by selecting standoff weapons or high altitude deliveries.
- Saturate enemy air defenses by routing several attacking aircraft at the same time over defense site.
- Employ ECM in the form of chaff, jamming, or anti-radiation missiles to degrade the performance of enemy defenses.

These and other options have important implications for viable weapons planning for air strikes. The probability that each weapon delivery will actually be accomplished must be considered in the computation of an optimal weapons mix. Weapons and aircraft must be assigned to ECM and defense suppression at the cost of assigning less weapons and aircraft to other targets. All of these interrelations and restrictions contribute to a formidable optimization problem.

3.4.2 System Structure

In arriving at solutions to the anticipated variety of weapon allocation problems, it is necessary for a planning aid to offer flexibility of operation and the capability to restrict variables according to resource limitations and other operational constraints. Differences in operational concepts, targeting directives, and strike planners' experience call for flexibility in value modeling options and in the anlaysis capability offered by a strike planning decision aid. Recent research with a decision aid for air strike timing (Siegel and Madden, 1980) has determined that some experienced naval strike planners prefer not to use value models for analysis of simulated air strike outcomes. However, other planners in the same study found the value model in the experimental decision aid helpful. It is possible that subjects who did not favor the value model may have been rejecting the specific value parameters used in the experimental problems rather than the general concept of a value model. One value model would be especially useful for weapons allocation decisions in quantification of the relative priorities of different targets. Another value model could be applied to the losses of strike force aircraft in order to provide the planner with an aggregated estimate of his losses. Whether or not these two value models can be made sufficiently commensurable so as to justify combining into a single scale of strike value is an issue best left to the discretion of the strike planner and his knowledge of the situation.

The approach to these problems, termed the Weapons Allocation Aid for Strike Planning (WAASP), uses a modular concept as shown in the functional organization illustrated in Figure 3-2. The Executive serves to coordinate the other system modules and interface them with the user. The Executive prompts the planner to select analysis and modeling options, to supply basic strike planning data and to generate complete weapons plans. Process models for determining effectiveness of air-to-surface weapons (from AWOP), surface-to-air weapons, and ECM options are configured according to user inputs to provide aircraft and target survival probability data for the WAASP strike simulators. If the planner assigns relative values to enemy tagets and/or to strike aircraft, the Executive oversees the formulation of appropriate value models and analysis directives for the strike simulators.

Two alternative strike simulators are visualized in WAASP -- a deterministic simulator and a stochastic simulator. The deterministic simulator treats probabilistic events as producing expectations of uncertain results in order to support rapid analysis of initial, tentative strike plans. The stochastic simulator samples all probabilistic events in Monte Carlo fashion to provide more accurate estimates of strike results along with estimates for the uncertainty around expected results. Because the stochastic simulator operates much more slowly than the deterministic simulator, the stochastic simulator is more appropriate for detailed comparative analysis of a few strike plans developed with the aid of the deterministic simulator. Outputs of the simulator may be displayed to the user in raw form or in terms of the results of user-selected analysis procedures designed to locate the weak points in each strike plan. Simulation outputs may also be processed by a heuristic model that suggests specific ways for improving the strike plan. WAASP outputs are displayed to the user on graphic and alphanumeric CRT monitors that are driven by a WAASP module for display generation.

WAASP employs techniques developed and tested throughout the ONR ODA program for displaying information to the planner. Both graphic and

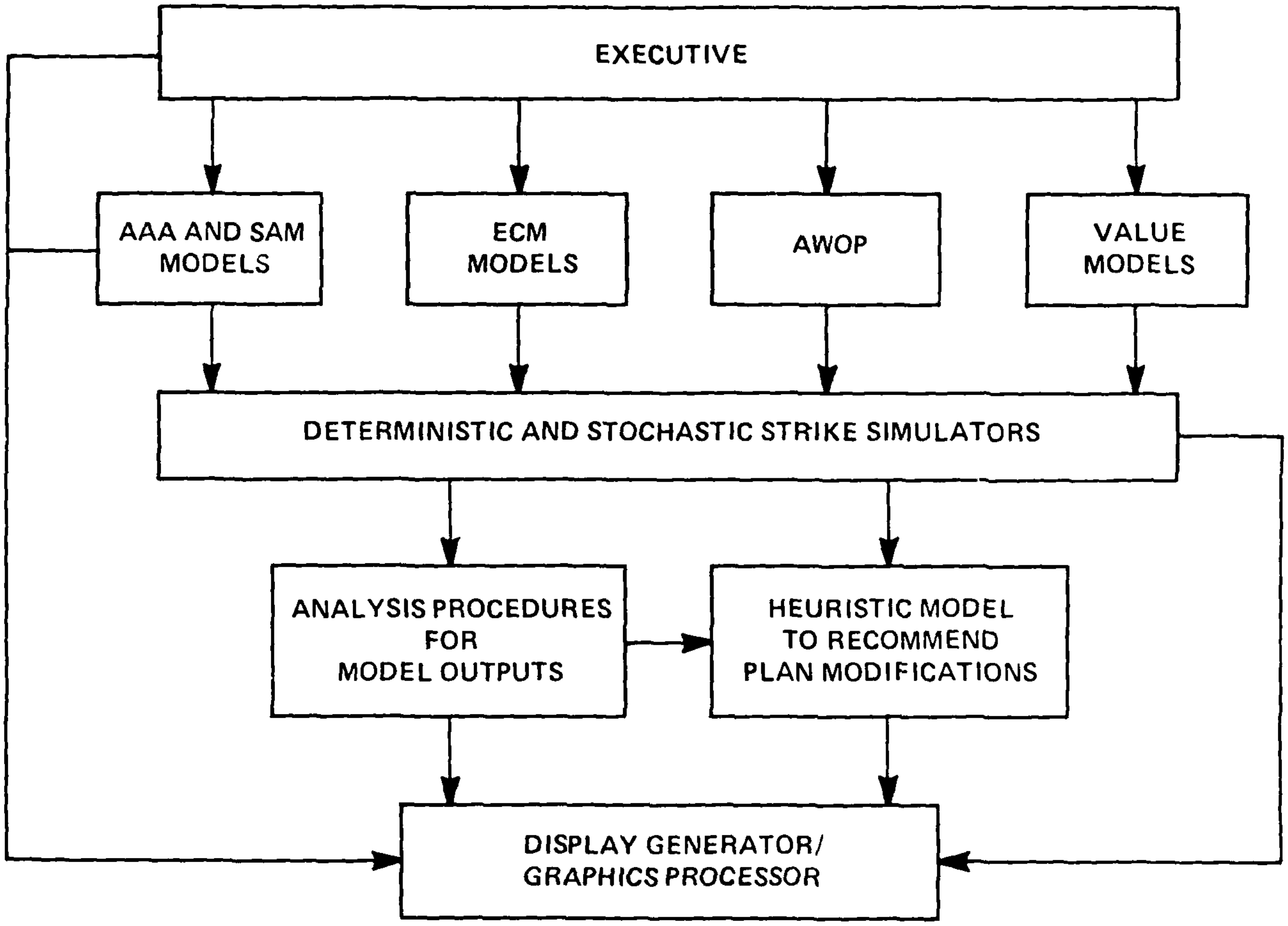


Figure 3-2. Structure of WAASP

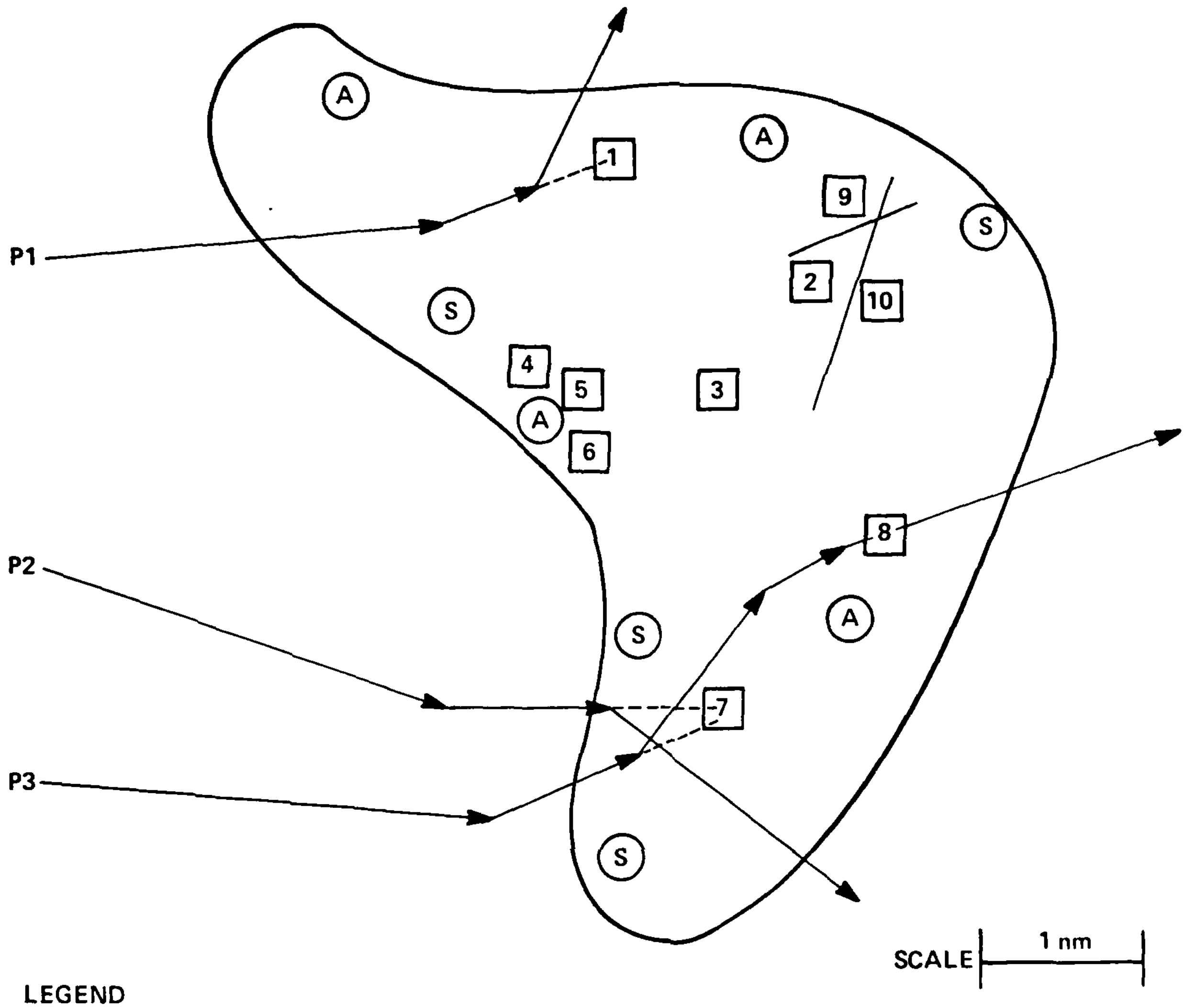
alphanumeric CRT terminals are used. Comparative numerical data are presented in both tabular and bar-graph forms. Planning options are displayed to the planner at each choice point and extensive on-line assistance is available to explain abbreviations and interpretations of variables. A map display of the target area, illustrated in Figure 3-3, depicts the location of targets, ground defense sites, and the vectors for the planned attacks. Each flight path on the display consists of approach, attack, and exit vectors designated by the planner. Multiple attacks can be planned for a single sortie as represented by attack vector P3, for which the exit vector from the attack on Target No. 7 leads into the attack vector on Target No. 8. The paging capability of the Grinnell color graphics system in the ODA test bed is valuable in enabling the separation of the flight path displays from one another and from the basic map display so that a change to one situational item does not require regeneration of the entire display. Paging is also used to overlay the map display with a grid in which the varying intensity of a single color codes the exposure of attack aircraft to enemy ground defenses. The color intensity of a grid square represents the probability of an attack aircraft becoming disabled by enemy ground defenses during a specified unit time within that square.

3.4.3 Usage of WAASP

WAASP could be applied to solving a diversity of strike planning problems:

- In one scenario, the planner is advised what targets are to be attacked and what probabilities of kill (P_ks) are to be achieved; if aircraft and weapons are limited then the object is to establish a plan that produces the specified P_ks. If resources are less restricted, then the solution could be a plan that minimizes use and attrition of resources while still resulting in the desired P_ks.

- In other cases, the P_k value for each target may be determined by the planner so as to satisfy operational concepts that envisage the destruction of a percentage of all targets combined or that call for maximum destruction of all targets with limited available strike resources.



LEGEND

(S) – SAM SITE

(A) – AAA SITE

TARGETS:

1	– FUEL DEPOT	6	– BARRACKS
2	– ATC TOWER	7	– ORDNANCE DEPOT
3	– HANGAR	8	– AIRCRAFT REVETMENT
4	– ADMINISTRATION	9	– RUNWAY
5	– BARRACKS	10	– RUNWAY

ATTACK PATHS:
P1 – A7E, LOAD 6
P2 – A7E, LOAD 4
P3 – A7E, LOAD 7

Figure 3-3. WAASP Map Display for Target Area

- In still other cases, the planner may need only to estimate and perhaps minimize attrition of the strike force by enemy ground defenses.

The manner in which WAASP would aid weapon allocation problems is best illustrated by the general procedural flow in Figure 3-4. Different strike planners and different strike situations generally call for somewhat different analysis procedures either with or without WAASP. The WAASP Executive configures the processing flow according to the options selected by the user:

- The weapons analysis generally begins with description and location of principal targets, inventory of available weapons and aircraft, and identification of feasible weapon delivery conditions (Box 1). Most of this data can be prepared, at least tentatively, well in advance of the time of the planned strike (e.g., as the task force deploys to its designated area of operations).

- AWOP is then used to generate tables that will indicate the probability (P_k) that each target will be incapacitated to a specified extent by each weapon delivery (Box 2). In addition to a P_k value, each record in the AWOP output table indicates type of weapon, type of fuze, type of aircraft, type and dimensions of target, desired damage to target, number of weapons launched per attack sortie, delivery speed and angles, and weapon aiming errors.

- Enemy ground defense sites are characterized and localized in the same way as the principal targets. (Box 3).

- ECM options are then identified (Box 4) and used to determine survival probability parameters for attack aircraft (Box 5). The probability parameters determined in Box 5 provide inputs to subsequent modeling steps, but do not represent total aircraft survival probabilities because complete paths of attack have not yet been defined.

- Possible attacks on ground defense sites can be defined (Box 6) and estimated results can be determined using AWOP (Box 7), but attacks that are contingent on sustained electronic emissions by the ground defense (e.g., anti-radiation missiles home on the defense site radar) are probably best modeled like other ECM options as a uniform degradation in ground defense effectiveness.

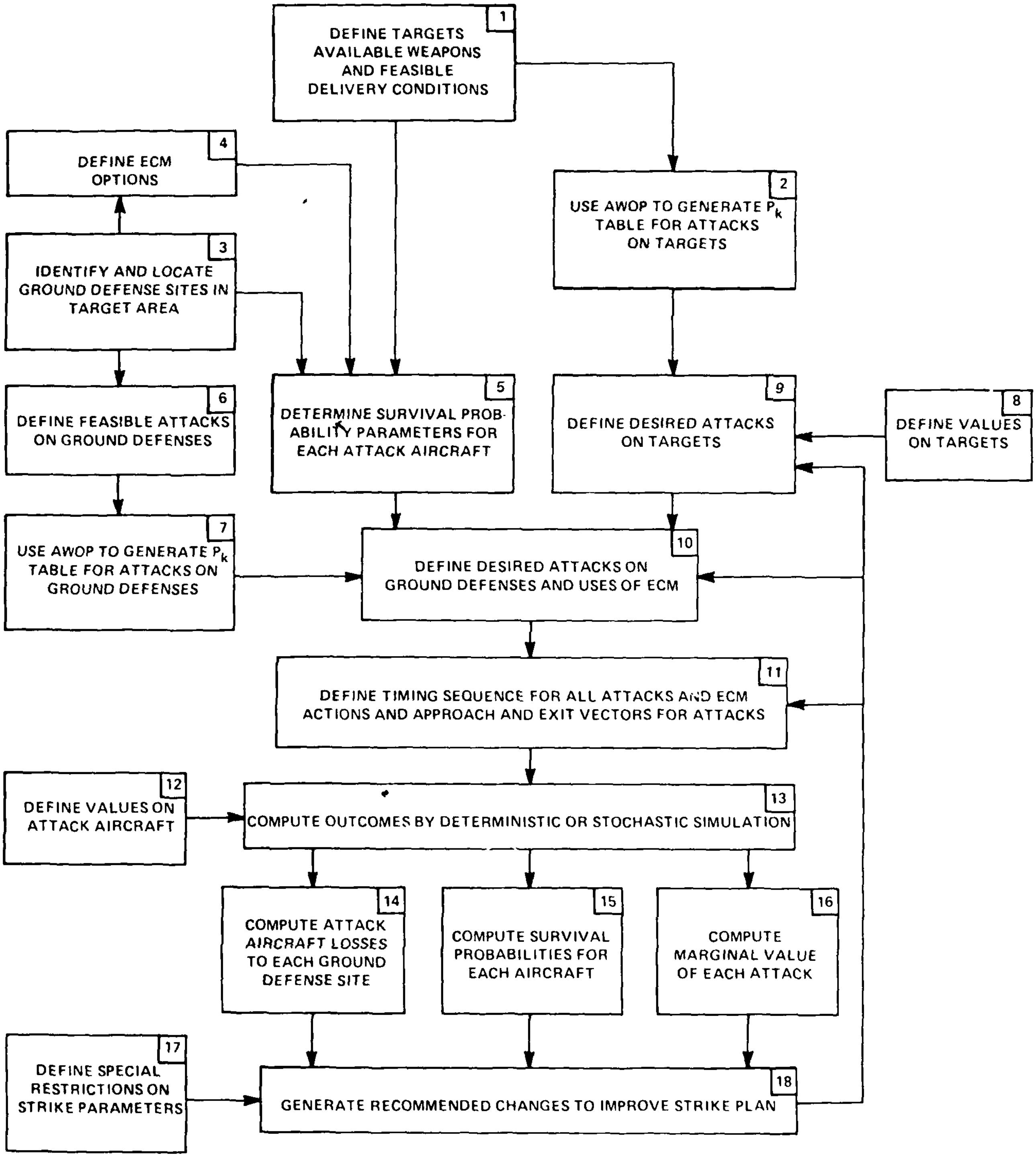


Figure 3-4. Procedural Flow for Use of WAASP

- Relative values may be assigned to the targets (Box 8) to help in selecting desired attacks (Box 9) from the AWOP table for attacks on targets.

- Uses of ECM and attacks on ground defenses can then be selected (Box 10) to enhance survival probabilities for the attack aircraft.

- The relative timing of all attacks against targets and ground defenses is then defined along with ECM plans and approach and exit paths for attacks (Box 11).

- Relative values amy be assigned to distinct attack aircraft (Box 12) in order to aid in trading-off attrition of different aircraft or to aid in weighting strike force losses against destruction of enemy targets.

- The complete strike can then be simulated (Box 13) using either the deterministic or the stochastic mode.

Intermediate results such as unit survival probabilities are made available to the user wherever they might be useful in order to support unanticipated applications.

The outputs of the simulation can be analyzed in a variety of ways to develop indications of where the strike plan is deficient and how it might be improved:

- Predicted aircraft losses to each ground defense site (Box 14) can be used to reroute attacks or to develop a revised ECM plan.

- Predicted survival probabilites for each aircraft for each attack segment (Box 15) can also be useful in modifying routing and ECM plans.

- If a value model has been defined over targets, then the marginal value associated with each attack can be determined (Box 16) to suggest which attacks might be eliminated without seriously compromising the strike effectiveness.

- All of these special analyses may be used along with any special restrictions imposed by the user on the strike parameters (Box 17) as inputs to a heuristic model.

- The heuristic model generates recommendations for the improvement of the strike plan (Box 18).

Individual variations in decision-making style and in the characteristics of the strike situation require that WAASP offers a fair degree of flexibility in the flow of processing. Some may prefer not to employ value models on attack aircraft and/or targets. In some cases, planning for effective suppression of enemy defenses may be the prime concern while in other cases the determination of acceptable approach and exit paths for attack aircraft may be most important. To support such differences in problem structure and focus, WAASP would make some inputs optional and provide outputs at every stage of processing so that the analysis procedure can be truncated at any point in Figure 3-4. Thus, WAASP could be used discriminatively to generate estimates of the success probability of individual target attacks or estimates of the probability of specific sorties penetrating a given ground defense.

4. CONCLUSIONS AND RECOMMENDATIONS

This report has described the design of an air strike plan decision aid system integrating ideas and techniques developed in the ONR ODA program. The general air strike planning problem was structured to identify and classify objectives, constraints, decisions, and influencing factors. Using the structure, decisions were divided into five problem areas: target selection, weapon allocation, mission formation and assignment, mission routing and scheduling, and contingency planning. A decision aid system called the Air Strike Planner (ASP) was designed so that a flexible approach to strike planning may be taken, enabling the strike planner to attack the decision area in any sequence and level of detail desired. To describe at a more detailed level the ASP approach to a strike planning aid, the weapons allocation portion of ASP was described as a stand-alone aid called the Weapons Allocation Aid for Strike Planning (WAASP). Special attention was given to areas where ODA aids, techniques, and principles might be suitably applied.

In the course of the study, decision aids for air strike planning were investigated with respect to functional requirements and feasibility of implementation. It was proposed that ASP should include whatever functions would be helpful to an air strike planner as long as the functions could plausibly be implemented within current technology. Consequently ASP represents a superset of state-of-the-art decision aid functions applicable to strike planning. The comprehensive scope and attendant complexity of the ASP concept, however, would require a very large effort to implement an operational ASP system. Accordingly, it is appropriate to investigate the potential costs and benefits associated with each proposed ASP function. In

particular for each decision function addressed by ASP, the following three issues should be considered:

- Importance of the decision function.
  The potential impact of timely and optimal performance of each decision function on overall strike plan success should be evaluated so that high-cost, low-impact aid functions could be deleted.

- Benefit of aid.
  An aid may prove beneficial to a decision process basically in two ways -- improvement in the quality of the selected alternative and reduction in the time or effort needed to reach a satisfactory decision.

- Cost of aid.
  The cost of an aid includes labor and resource costs of implementation and maintenance of the system and manpower, computer, and communications costs associated with operational use of the aid.

This evaluation of proposed aid functions must depend heavily on expert judgement. Particular effort should be devoted to determining from experienced air strike planners the relative severity of the various problems currently faced in strike planning and the estimated benefits that would derive from the availability of candidate aiding concepts.

Such evaluation may be initiated by analyzing importance, benefits, and costs on a function-by-function basis. However, the interactive effects among the elements of a decision aid system require the evaluation of entire decision aid system concepts rather than a piecemeal element-by-element analysis. Interactive cost effects are especially evident; for example, the cost of building a single geographic map system for the display-target-sites and display-detection-contours functions is less than the sum of the costs of building a separate map system for each function.

By synthesizing reasonable design alternatives, several strike planning decision aid system concepts should be developed for this evaluation

process. These system concepts should exemplify and highlight the variety of capabilities made possible within the broad ranges of cost and functional complexity. The opinions expressed by strike planning experts on these concepts will prove valuable in guiding the development of future decision aids.

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